Nanotechnology Approaches to Sensing and Detection

Dr. James S. Murday

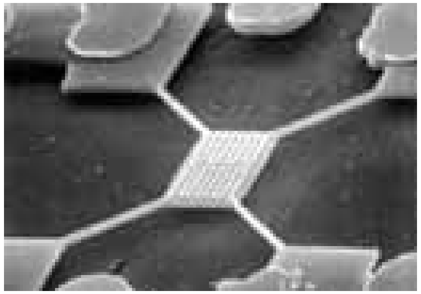
Dr. Richard J. Colton

Naval Research Laboratory

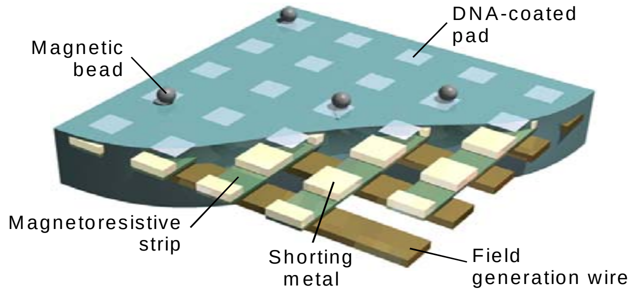
Washington, DC 20375-5342

rich.colton@nrl.navy.mil

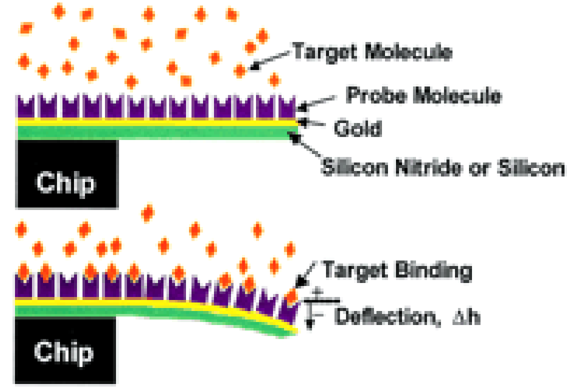
Why Nanostructures for Sensing



Nanocalorimeter; Roukes CIT



GMR Biosensor; Whitman/Prinz, NRL



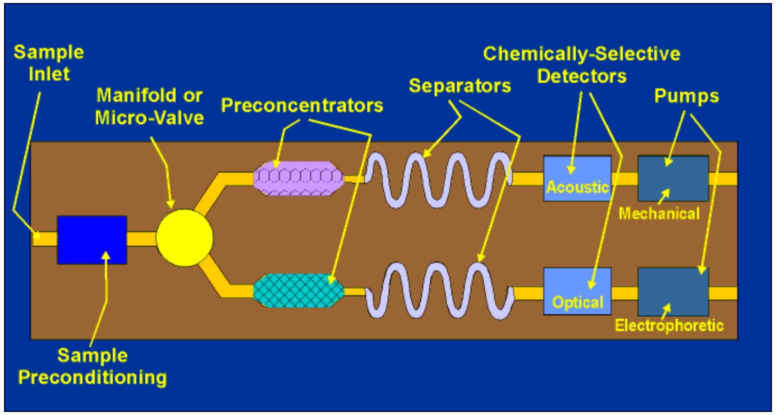
Cantilever Sensor; Thundat ORNL

- Signal to noise improvements:

  yocto(10^{-24})joule,

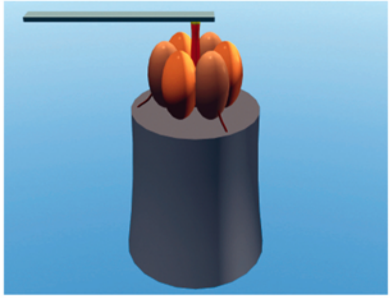
  atto(10^{-18})newton,

  single molecule, ….

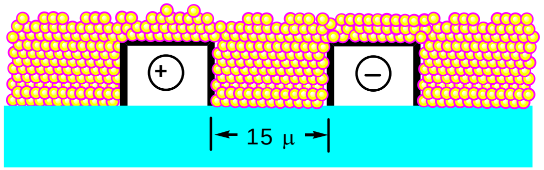


Lab-on-a-chip; Sandia

- Miniaturization – size/weight - arrays
- Lower power, potentially scavenged
- Locally process data into information



Molecular Motor; Montemagno Cornell



NanoAu Chemiresistor; Snow NRL

Nanotechnology Approaches to Sensing & Detection

Outline

- Approaches
  - Electron tunneling transducers (STM inspired)
  - Micromechanical detection (AFM inspired)
  - Nanowire/tube
  - Nanoparticle
- Power sources
- Looking ahead

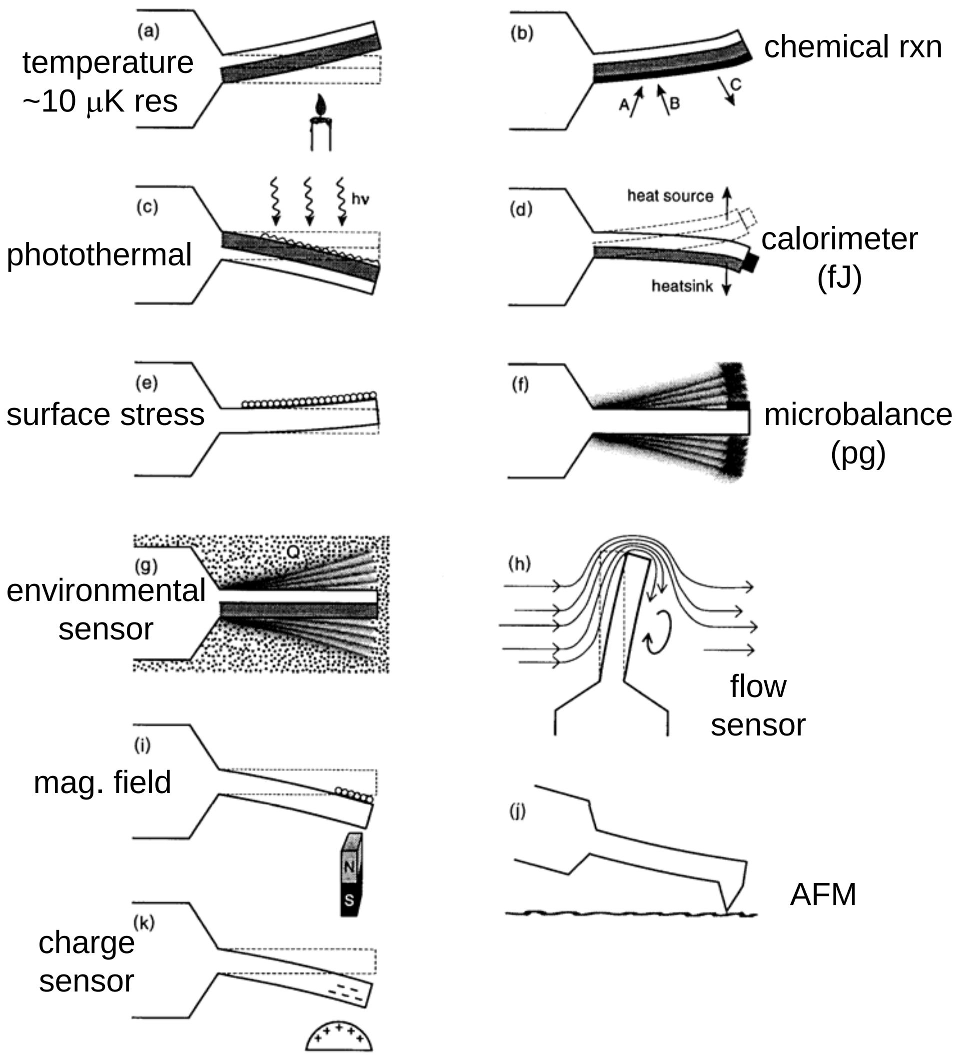
Micromechanical Approaches – AFM inspired

Thundat	ORNL	Protiveris – VeriScan 3000
Lang	IBM Zurich	Concentris – Cantisens
		Veeco - Scentris
Bashir	Purdue	
Craighead	Cornell	
Fadel	Univ Bordeaux	
Majumdar	UCB	
Whitman	NRL	
Ziegler	Univ Kaiserslautern	

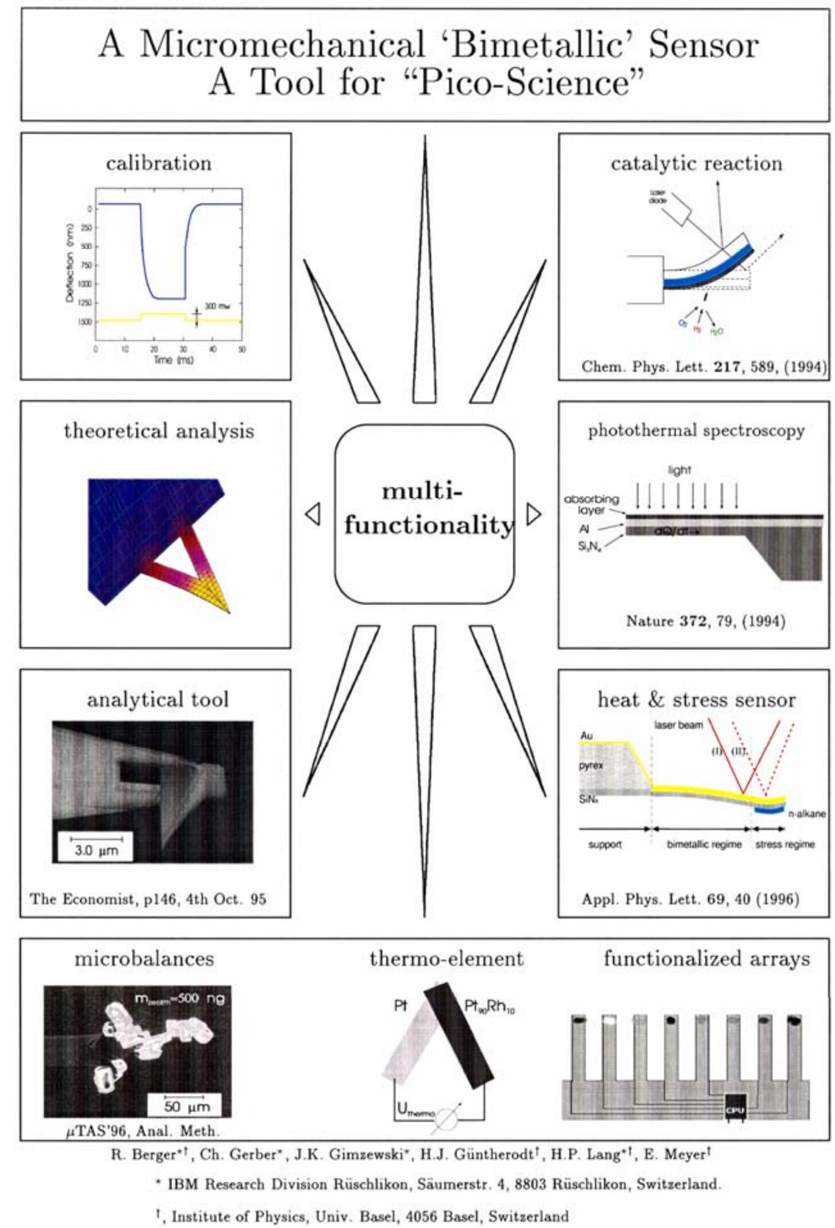
Cantilever Sensor Array Bibliography - http://www.veeco.com/pdf/CSA_Bibliography.pdf

Micromechanical Sensing & Detection

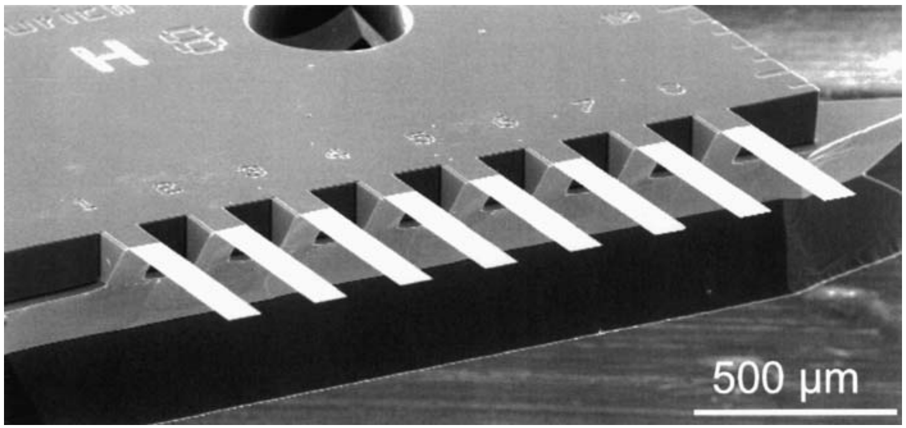
Micromechanical cantilevers

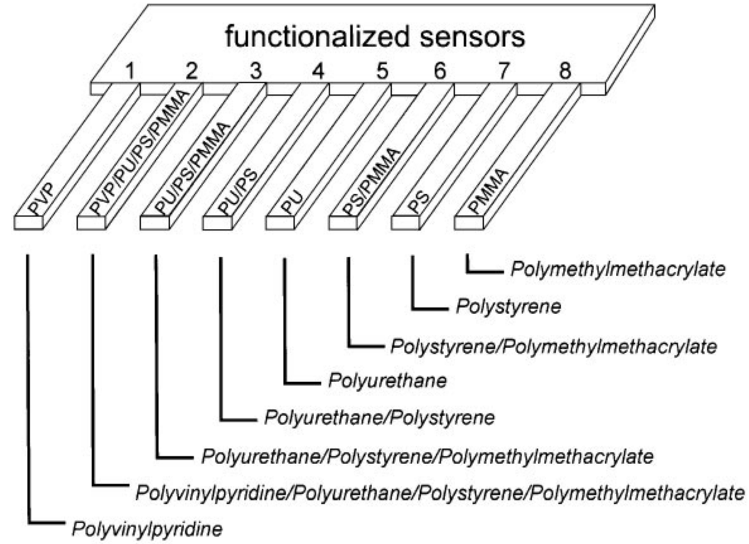


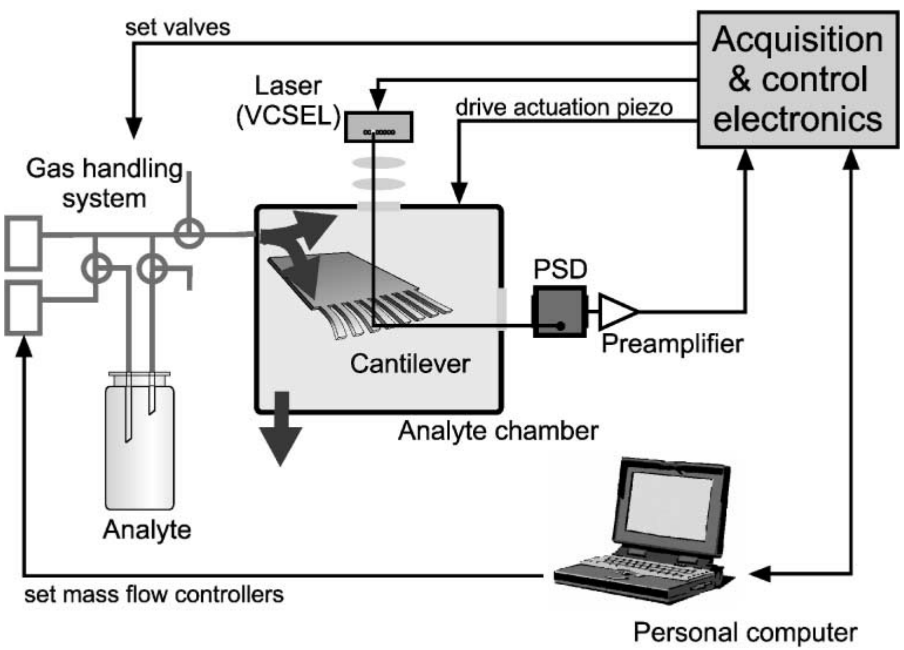
H.P. Lang, et al., *Anal. Chim. Acta* **393**, 59 (1999)

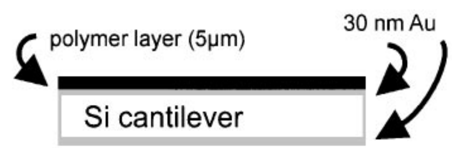


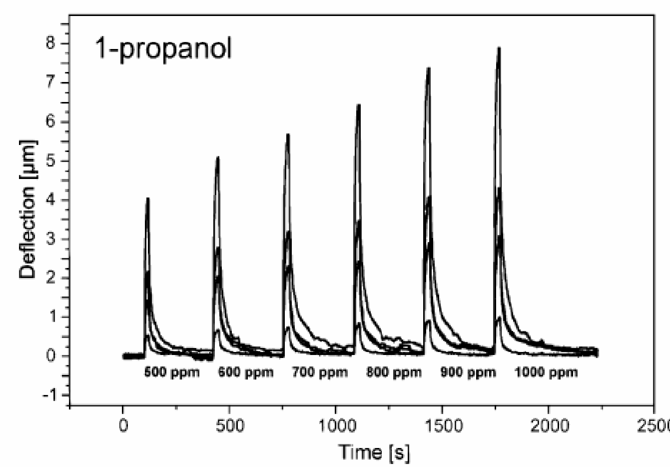
Cantilever Array-based Artificial Nose





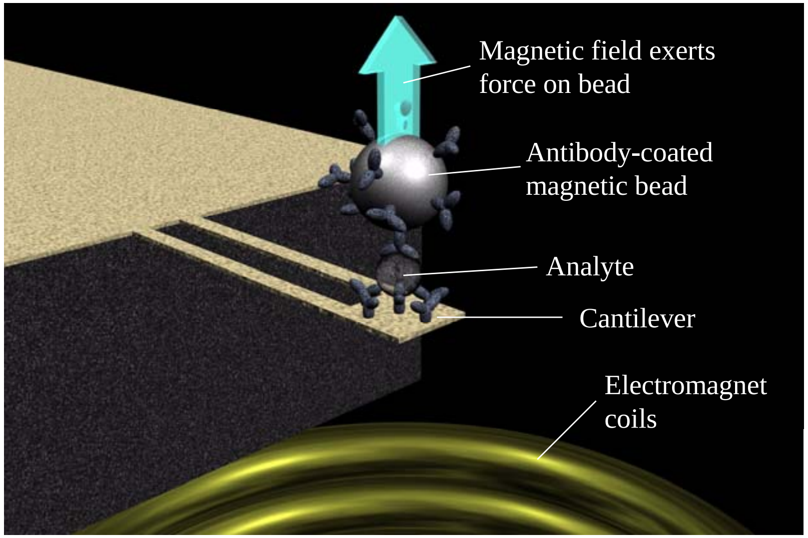




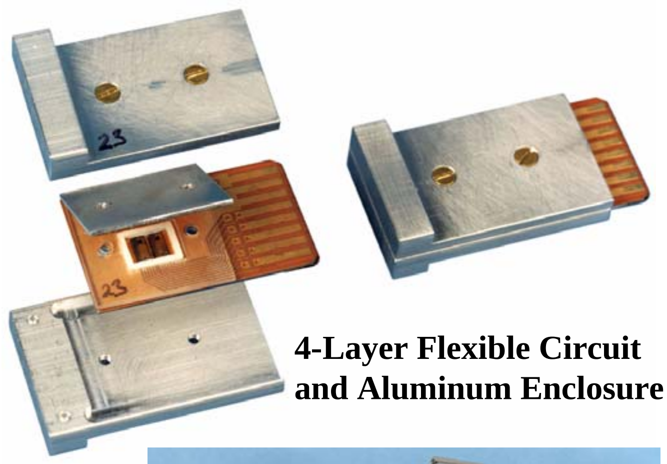


M.K. Baller, et al., *Ultramicroscopy* **82**, 1 (2000); F.M. Battiston, et al., *Sensors & Actuators* **77**, 122 (2001)

Force Amplified Biological Sensor



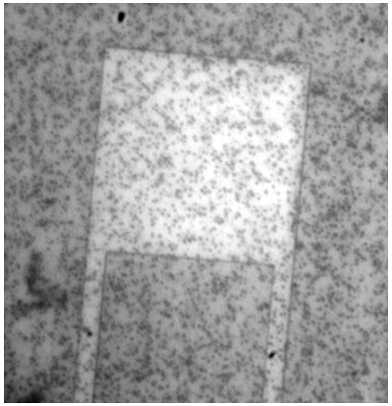
1 of 2
4-cantilever dies



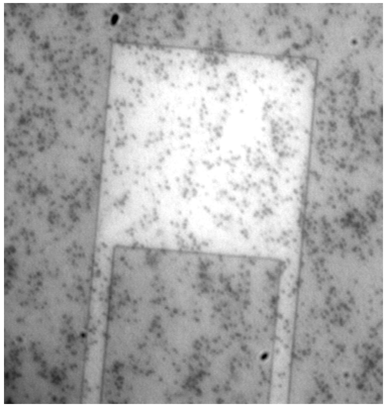
4-Layer Flexible Circuit and Aluminum Enclosure

FABS Assay for Ovalbumin at 1 ng/mL

Before magnetic field



After magnetic field



D.R. Baselt, et al. *JVST B* **14**, 789 (1996); *Proc. IEEE* **85**, 672 (1997)

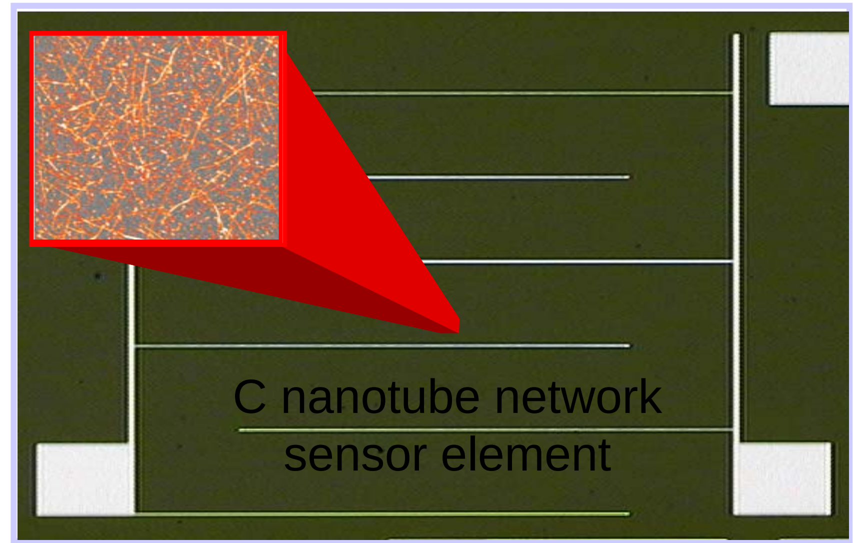
Nanowire/Nanotube Approaches

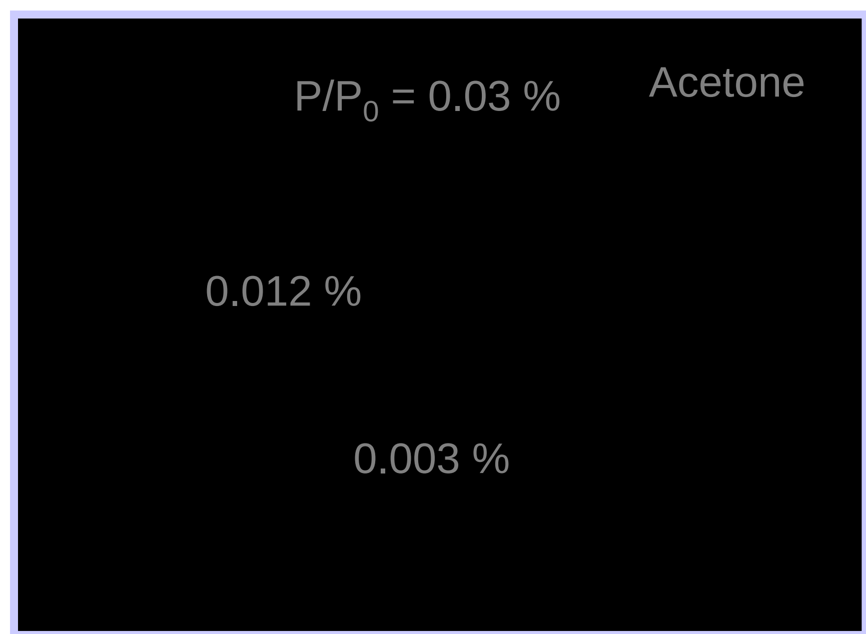
Dai	Stanford
Dekker	Delft (ND)
Grimes	Penn State
Lieber	Harvard
Snow	NRL
Valentini	Univ Perugia (IT)

Chemical sensing with C nanotube networks

E.S. Snow and F.K. Perkins

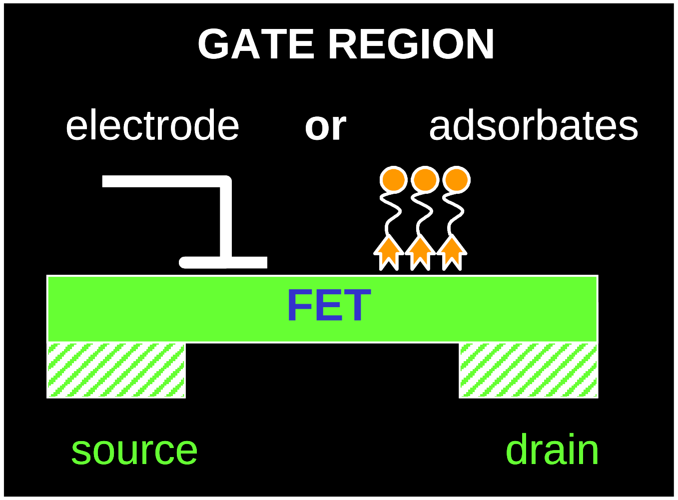
- Sensor based on capacitance of SWNT network
- Detection via field-induced polarization of adsorbates on SWNT surface
- Fast, low-power, and highly sensitive
- Responds to CWAs, TICs and explosives
- Chemical specificity achieved using chemically selective coatings
- Functionalized arrays for detection and identification





III. Biosurfaces on III-V Substrates for bioFETs

→ **Versatility**



An ideal surface chemistry would:

1. Preserve the electronic integrity of the underlying substrate while remaining thin enough for efficient sensing (~2 nm).

2. Allow for specific attachment of DNA or protein molecules.

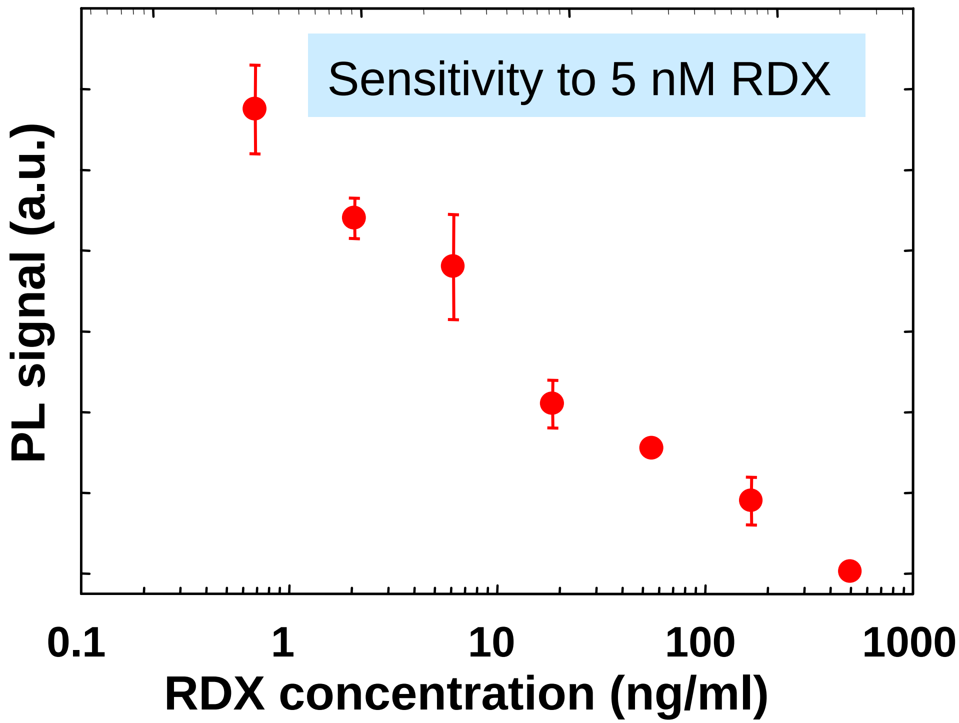
3. Resist the nonspecific adsorption of other biological materials (lower background & false positives).

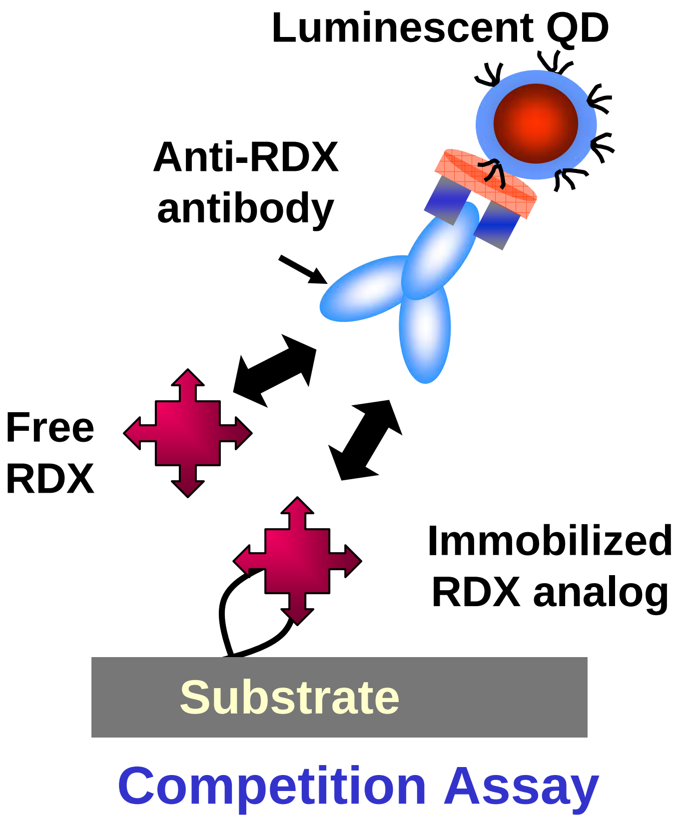
For many substrates (e.g. InAs, GaN), no such chemistry currently exists.

(Nano)particle Approaches

Alivasatos	UCB	Quantum Dot Corp – QDot Bioconjugates
Mirkin	Northwestern	Nanosphere, Inc - Verigene
Snow	NRL	Microsensor Systems, Inc
Whitman	NRL	Seahawk Biosystems
Lu	Univ Ill	
Tan	Florida	
Tan	Nanyang Tech Univ (PRC)	

Detection of Explosives (RDX) in Seawater



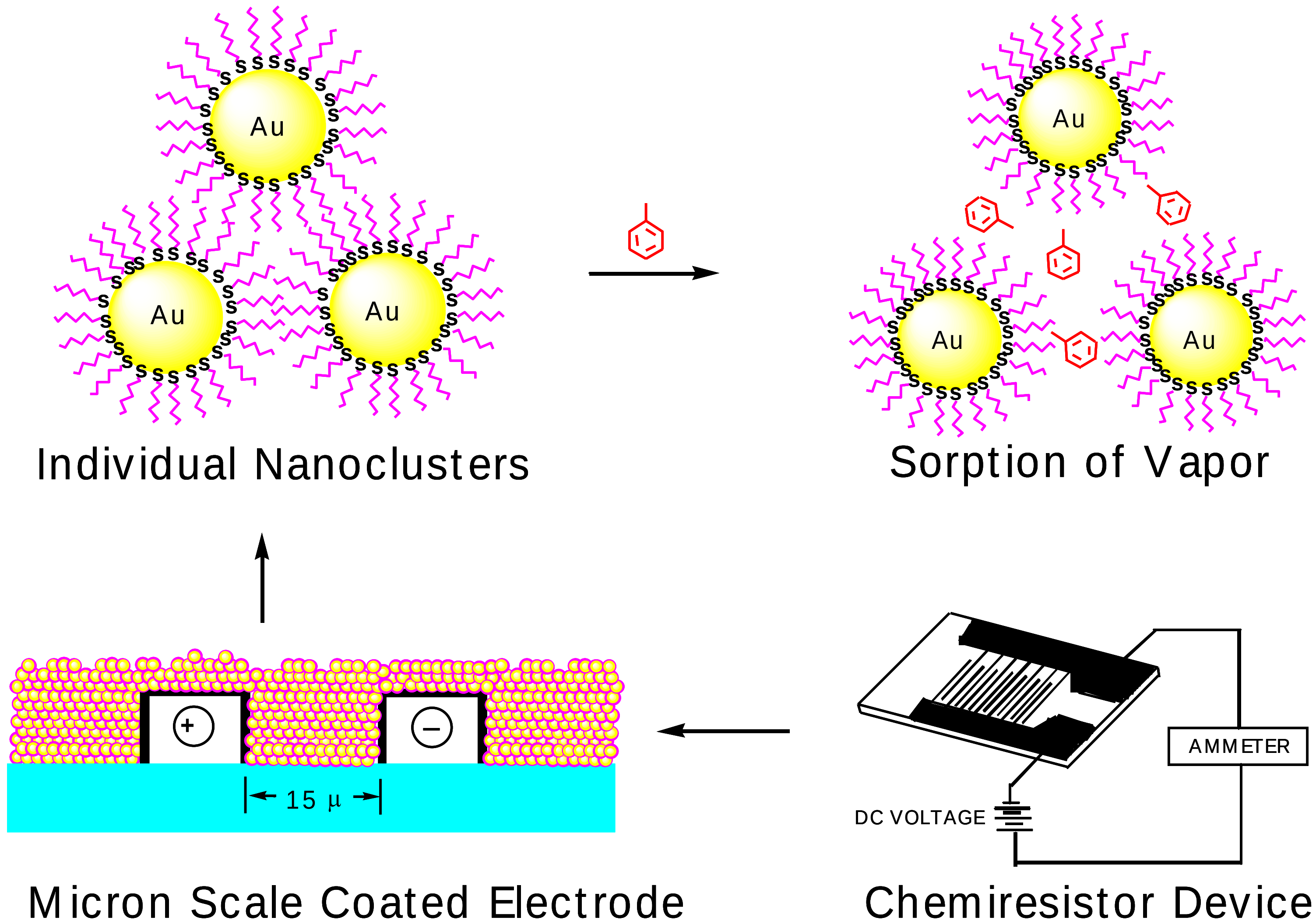


- Prepare QDs conjugated with anti-RDX antibodies
- Measure PL of QD-bioconjugates bound to a surface prepared with RDX analogs
- Free RDX competes for bioconjugate and reduces PL signal

E.R. Goldman, et al., *Anal. Chim. Acta* **457**, *13* (2002)
NRL, Code 6900

Also in solid & water environmental samples
E.R. Goldman, et al., *Environ. Sci. Technol.* **37**, 4733 (2003)

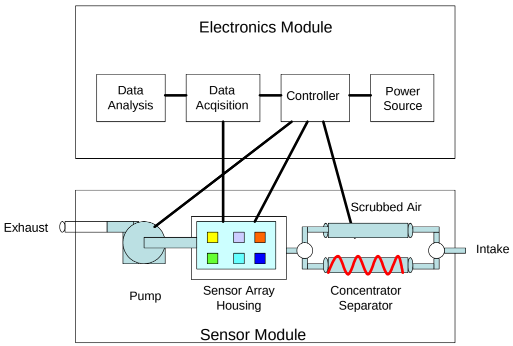
Gold Nanocluster Chemical Sensor



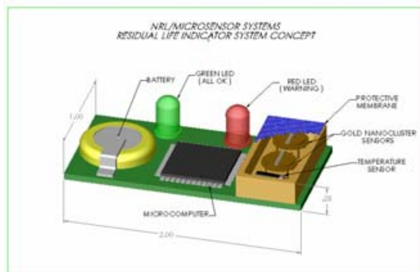
H. Wohltjen & A.W. Snow, *Anal. Chem*. **70**, 2856 (1998)

Hybrid Silicon Chip Integrated
MIME CW Agent Detection System

Schematic Sensor System Diagram



Artist's Depiction of a
Micro Residual life indicator



Current Version (125 g/3x2x1")
"cigarette pack size"

→

Future Version (10g/1x1x0.5")
"wristwatch size"

Targeted Applications
UAV Platforms
Residual Life Indicators
Drop-off Sensors

Objective:

- Accelerate miniaturization of new gold cluster based toxic chemical vapor detection system from a printed circuit board configuration to a light weight/small volume hybrid silicon chip integrated package with an ultralow power requirement.

Description:

- An ensemble of nanometer scale gold clusters serves as a highly sensitive and selective solid-state element for adsorption of chemical species and transduction to an electronic signal.

Description of Effort:

- This proposal is a joint NRL-MSI effort to fabricate an integrated detector system as a silicon chip hybrid:
- Integration of gold cluster vapor sensitive materials and transduction mechanism with planar silicon technology
- Fabrication of sensor and supporting components (electronics, microprocessor, etc.) on separate silicon chips connected by vapor lines and pneumatics
- Design for minimal power consumption (mW)

Benefit to Warfighter/First-Responders:

- Small size, light weight and low power consumption of this detector system permit unobtrusive incorporation into a garment, helmet or on a UAV.

Challenges:

- Develop self-assembly chemistry for incorporation of gold cluster vapor responsive component into a silicon chip
- Reduce of supporting electronics and microprocessor functions to integrated silicon chip package
- Miniaturization/incorporation of vapor lines and pneumatics
- Integration/programmed electronic control of detector system

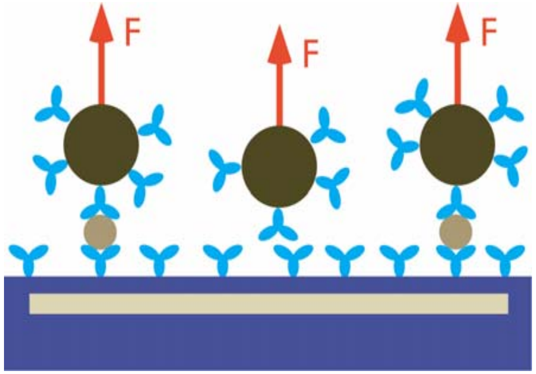
Maturity of Technology: **Applied Research (6.2)**

Business Area: **Chemical Point Detector**

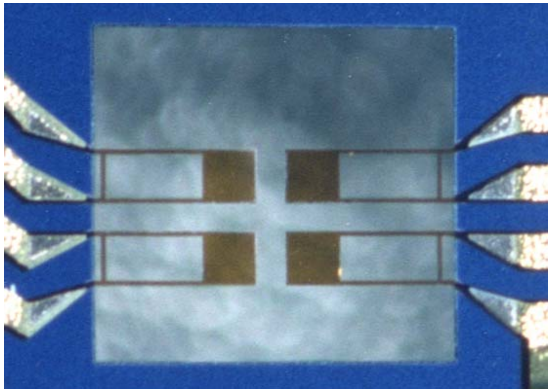
NRL POC: Dr. Warren Schultz, 202-767-2479
Dr. Art Snow, 202-767-5341

Single Molecule Biosensors

Force Discrimination Assay

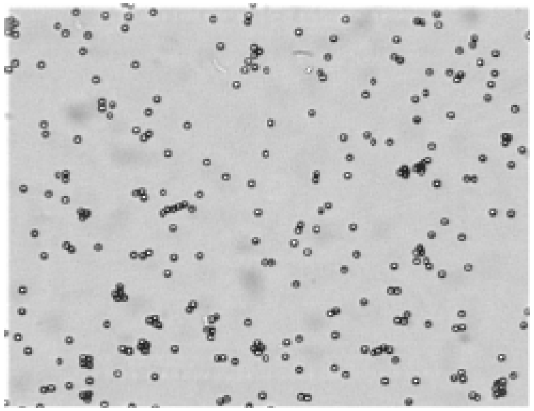


Biosensor Platforms



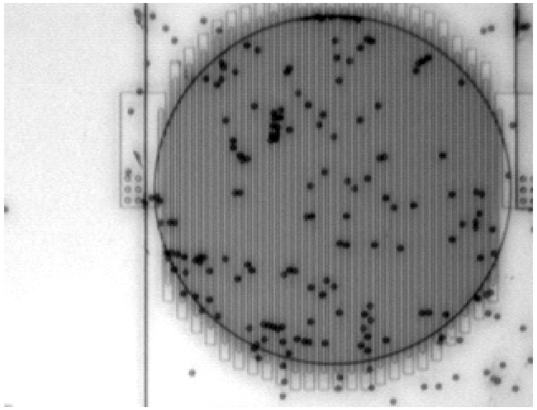
Piezoresistive cantilever
FABS

D.R. Baselt, *et al., Proc. IEEE* **85**, 672 (1997)



Transparent substrate with optical detection
FDB

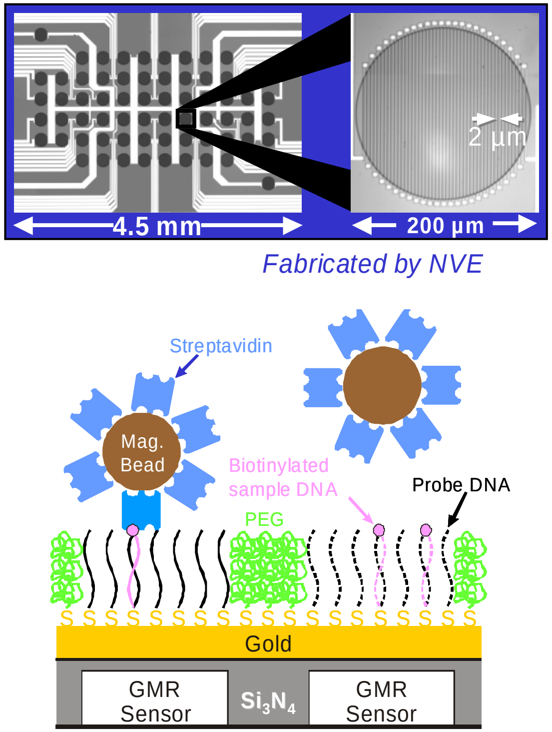
G.U. Lee, *et al*., *Anal. Biochem*. **287**, 261 (2000)

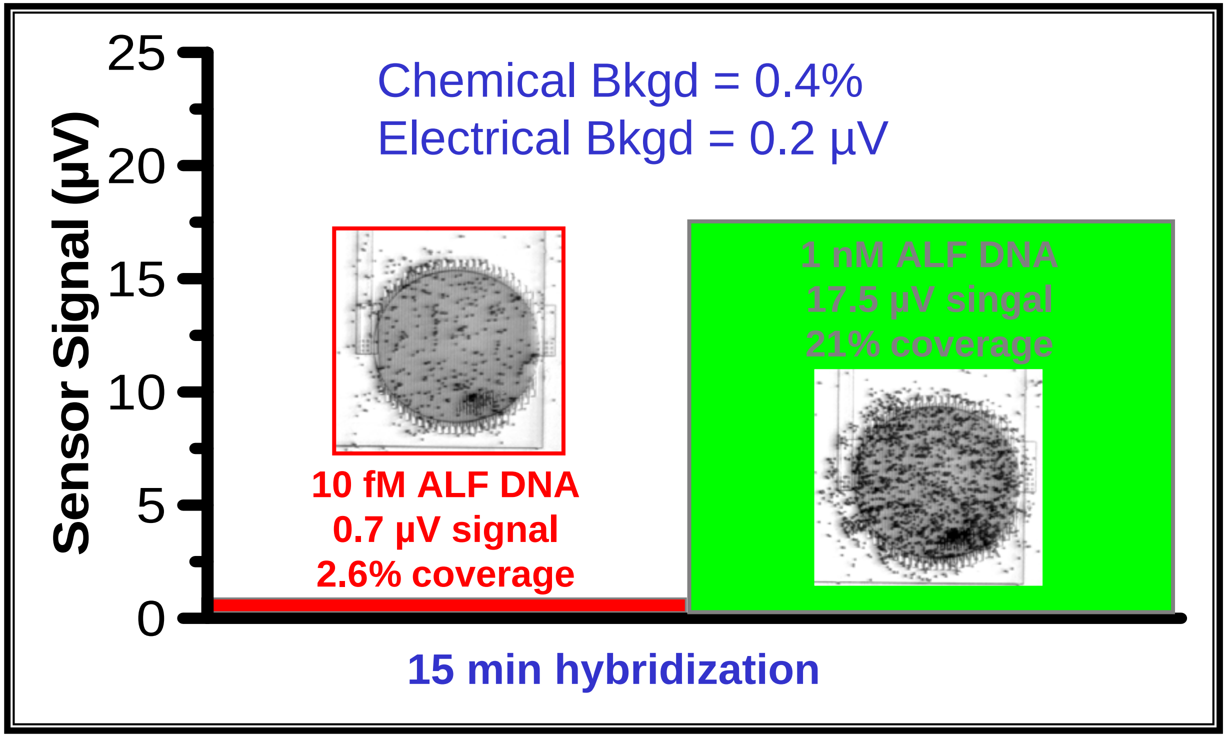


Magnetoresistive elements
BARC

M.M. Miller, *et al., J. Mag. Mag. Mat.* **225**, 138 (2001)

Bead Array Counter





- Demonstrated sensitivity <1 fM in ~30 min total assay time
- Integrated prototype completed, licensed for environmental monitoring (Seahawk Biosystems)

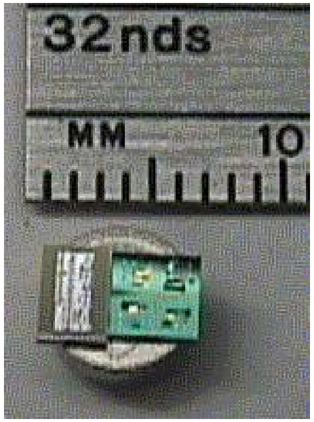
J.C. Rife, et al., *Sensors & Actuators A* **107**, 209 (2003)

Power Sources

NSF MPS-IC Workshop on Approaches to Combat Terrorism 19-21 Nov 2002

Opportunities for Basic Research in Energy and Power Sources

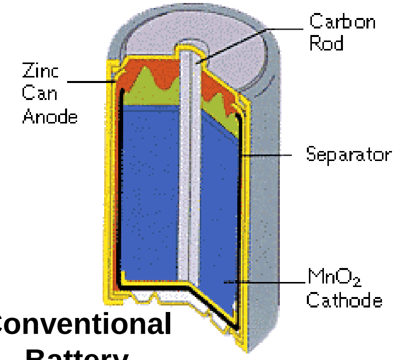
http://www.nsf.gov/pubs/2003/nsf03569/nsf03569.htm



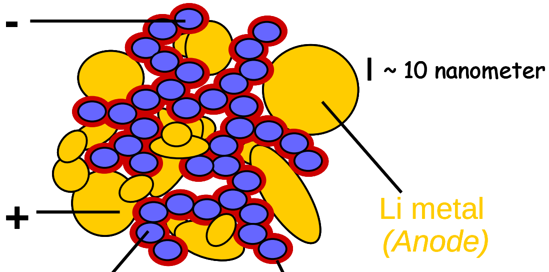
Smart Dust
K. Pister, UC Berkeley

K.E. Swider-Lyons & coworkers, "Power Sources for Nanotechnology," *Int. J. Nanotechnology* **1**, 149 (2003)

Replacing conventional battery architecture with new 3-dimensional nanostructured architecture …



Conventional Battery

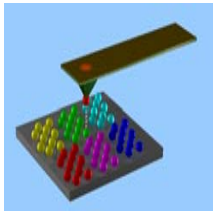


3-D Nano Battery

D.R. Rolison & coworkers, *Nature* **406,** 169-172 (2000)

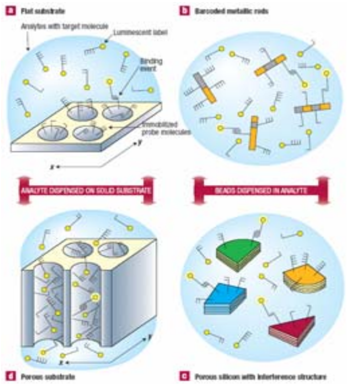
…to achieve higher battery capacity and energy density

Looking Ahead

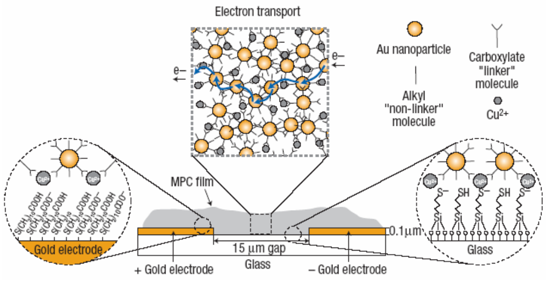


J-B.D. Green, *Anal. Chim. Acta* **496**, 267 (2002)

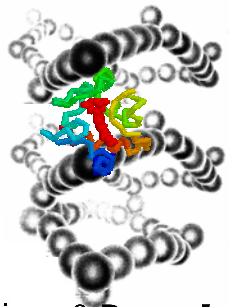
- **Nanoscience**
  - Single molecule imaging, spectroscopy (e.g., near-field vibrational spectroscopy), force measurements (e.g., binding affinity) & manipulation (via probes & tweezers)
  - Sample collection & handling issues for ‘single molecule sensors’
  - TeraHz standoff imaging and detection
- **Nanomaterials**
  - Nanoparticles & rods (e.g., barcoded molecules)
  - Nanostructured materials (e.g., aerogels & tubules) for sensing and energy storage/generation
  - Top-to-bottom functional design (e.g., directed self-assembly of organized networks of nanoparticles)



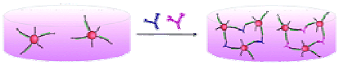
V. Lehmann, *Nature Mater.* **1**, 12 (2002)



R. Murray & coworkers, *JACS* **124**, 8958 (2002); D.R. Walt, *Nature Mater.* **1**, 17 (2002)

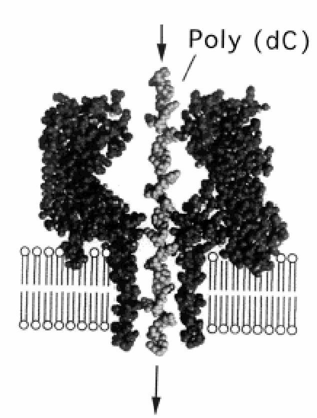


Rolison & Dunn, *J. Mater. Chem.* **11**, 963 (2001)



C.A. Mirkin & coworkers, *Science* **301**, 1884 (2003)

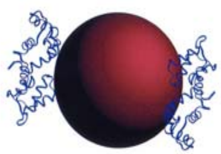
Looking Ahead

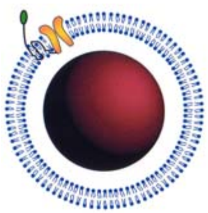


D.W. Deamer & D. Branton, *Acc. Chem. Res.* **35**, 817 (2002)

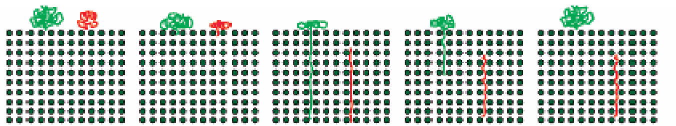
- **Nano(bio)electronics**
  - Biotic:Abiotic interface studies
  - Magnetoelectronics
  - Natural & synthetic ion channels & pores

- **Biosensors (→ BioNEMS & other NanoDevices)**
  - Micro- & nano-fluidics (i.e. sample collection/delivery)
  - Specialty proteins (e-protein; QD-protein)
  - Single molecule detection; single molecules as sensors





- **Lsboratory on a Chip**



H.G. Craighead & coworkers, *Anal. Chem.* **74**, 5169 (2002)

rich.colton@nrl.navy.mil